TITLE
ASP Conference Series, Vol. **VOLUME***, **YEAR OF PUBLICATION**
NAMES OF EDITORS

Indirect searches for SUSY Dark Matter with the MAGIC Cherenkov Telescope

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Abstract. Neutralinos are the natural well-motivated candidates to provide the non-baryonic dark matter of the universe which may produce detectable signals through their annihilation into neutrinos, photons or positrons. Due to its high flux sensitivity and low energy threshold, the MAGIC Cherenkov telescope could potentially detect the neutralino annihilation high energy photon products. In the framework of minimal supergravity, the neutralino SUSY parameter space can be scanned in different benchmark scenarios defined after accelerator and cosmology constraints. Moreover, the neutralino density profiles in galaxy halos and sub-halos have to be understood to infer which is the optimal observation region to be explored by the MAGIC telescope for the detection of neutralino photon signatures within our Galaxy and our Local Group.

1. Introduction

Observational cosmology is showing us a universe which is almost dominated by dark matter. Revealing its nature constitutes one of the most challenging questions of modern cosmology and particle physics, both from the theoretical and the experimental sides. A Cold Dark Matter scenario (CDM) in which the non/baryonic matter contribute to approximately 27% of the universe energy density content is presently widely accepted. Weakly Interacting Massive Particles (WIMPs), non-relativistic relics from the early universe, are good candidates to account for dark matter. Any of the known particles have to satisfy the requirements of being weakly interacting, massive and stable enough to be a relic particle. Supersymmetric (SUSY) extensions of the Standard Model of particle physics provide a particle that can accommodate all the requirements: the lightest SUSY particle (LSP), which turns out to be the neutralino in most of the SUSY-breaking scenarios.

Besides instruments based on the detection of the energy deposited by elastic nucleus-WIMP scattering in underground massive bolometers, others take profit of the fact that the neutralino is a Majorana particle and, therefore it can pair-annihilate producing high-energy neutrinos, positrons, antiprotons and

gamma-rays (Bergstrom et al. 2000). Unfortunately, so far there is no firm evidence by any of these techniques of a dark matter particle detection. Nevertheless, currently a new door is being open with new detectors which might be able to find the WIMPs. We will concentrate on the discussion of the MAGIC telescope potential: an instrument of a new generation of ground-based Imaging Air Cherenkov Telescopes (IACT), which might be able to detect gamma-rays from neutralino annihilations.

2. Spectral signatures of χ annihilations in Dark Matter halos

Neutralinos pair-annihilate through a variety of channels but for the present discussion only those that generate gamma-radiation in some intermediate or final state are of our interest. Annihilation processes like $\chi\chi \rightarrow \gamma\gamma$ and $\chi\chi \rightarrow \gamma Z$ generate spectral gamma lines. A distinct process is $\chi\chi \rightarrow q\bar{q}$, which generates a continuum of gamma-rays mainly by the decay of π^0-mesons produced within these jets.

Given a neutralino density profile $\rho_{CDM}(r)$ (i.e. the dark matter density profile within a galaxy), the expected differential gamma-ray flux from its annihilation along the observation line of sight is given by:

$$\begin{aligned} \frac{\Phi(E_\gamma)}{dE_\gamma} = \; & [N_{\gamma\gamma} b_{\gamma\gamma} \delta(E_\gamma - M_\chi) + N_{\gamma Z} b_{\gamma Z} \delta(E_\gamma - M_\chi(1 - \tfrac{M_Z^2}{4M_\chi^2})) \\ & + \sum_F \frac{dN_\gamma^F}{dE_\gamma} b_F] \frac{<\sigma v>}{2M_\chi^2} \frac{1}{4\pi} \int_{l.o.s} \rho_{CDM}(r) dr \end{aligned} \tag{1}$$

where N_i is the number of photons produced per annihilation channel (2 for $\gamma\gamma$, 1 for γZ and $n(E_\gamma)$ for the case of the continuum running over all the F final states), b_i are the process branching ratios, $< \sigma v >$ is the averaged product of total annihilation cross-section and relative velocities and M_χ is the neutralino mass. One should average all the flux contributions over the detector solid angle.

2.1. Modeling neutralino properties

In order to model the neutralino properties, a few SUSY scenarios can be considered. We restrict our attention to a constrained version of the Minimal Supersymmetric Standard Model (CMSSM), which incorporates a minimal supergravity scenario (mSUGRA) of soft supersymmetry breaking. In this context, given a set of input SUSY parameters at the Grand Unification scale, the whole spectrum of SUSY particles can be derived to low energies from the renormalization group equations of these parameters. This includes the neutralino properties as mass, annihilation cross-sections, branching ratios and particle spectrum from annihilations.

The precise electroweak data from LEP suggest that the Higgs boson should be very light, in good agreement with the prediction of MSSM models. Very accurate measurements of the gauge couplings are consistent with a supersymmetric Grand Unified Theory, if supersymmetric partners of the standard model particles weight less than about 1 TeV. Neutralino relic abundance falls naturally within the WMAP favored range, below this energy.

Several benchmark models to set the CMSSM input parameters were initially proposed to provide a common way to compare the SUSY discovery potential of future accelerators as LHC. The benchmark points have been recently re-defined after the very precise WMAP results. They have been chosen to fulfill conditions imposed by LEP measurements, $b \to s\gamma$ and the current relic density range Ω_{CDM}. With these constraints, the effective dimensionality of the CMSSM parameter space has been reduced (Battaglia et al. 2003). Indeed it is quite more reduced if the constraint from the anomaly on $g_\mu - 2$ measurement is also included in the analysis.

The most important direct experimental constraints on the MSSM parameter space are provided by LEP searches of SUSY particles and Higgs Bosons. Based on data-taking up to center-of-mass energy of 208 GeV, a lower limit can be set to the neutralino mass: of about 108 GeV. As this lower limit depends on calculation of the Higgs mass lower limit and the top mass measurement, a conservative lower bound would become to about 85 GeV, if one takes theoretical and measurement uncertainties into account (Battaglia et al. 2001). An upper limit on the neutralino mass can be set from the upper limit on the high accurate current Ω_{CDM} measurement, which imposes that M_χ is of about 400 to 500 GeV under mSUGRA (Ellis et al. 2003).

2.2. Modelling the Dark matter density profiles

Due to the small thermal velocity of CDM particles, their density fluctuations survive from the early universe on all scales. In this framework, N-boby simulations have shown that structures develop as small clumps collapse, undergoing series of merging that results in hierarchical formation of massive galactic dark matter halos, as the universe expands. The most massive halos are the hosts for baryonic systems such as Galaxies. According to this hierarchical clustering scenario, numerous dark matter satellites (sub-halos) of different sizes and masses are revealed to orbit the virialized massive dark matter halos (Klypin et al. 1999).

The CDM scenario predicts a larger number of sub-halos in galactic halos, more than known dwarf satellites of the Milky Way. This could be possible if there would be a large number of sub-halos being the known compact high-velocity clouds (CHVCs), which may possibly trace them. If neutralino is the dark matter candidate, it is interesting to correlate the locations of high-velocity clouds with the unidentified EGRET gamma-ray sources, and estimate how much Milky Way sub-halos potentially would emit gamma-rays by neutralino annihilation, which would have been detected by the satellite (Flix et al. 2003).

It is clear from (1) that the gamma-ray fluxes should be maximal for the closest densest dark matter regions of the universe, i.e, one would expect higher fluxes for cores of galaxies and sub-halos. How the density profile behaves at the very center is widely under discussion as more high-resolution numerical simulations are available. This is really fundamental because it affects directly the gamma-ray flux predictions.

Including the adiabatic compression of the dark matter due to baryonic infall during galaxy formation results in an increase of the central density of dark matter. This effect should be taken into account as an enhancement of the annihilation fluxes is expected (Prada et al. 2003).

3. Detection of dark matter with MAGIC

The 17 m diameter f/D=1 MAGIC telescope (Barrio et al. 1998) is the largest of the new generation of Imaging Atmospheric Cherenkov Telescopes. MAGIC is located at the Canarian island of La Palma (28.8 N, 17.9 W) at the Roque de los Muchachos observatory (ORM), 2200 m above sea level. It detects gamma-rays in the high energy regime with an energy threshold of about 30 GeV, providing much larger effective areas (and much superior sensitivity, of about 10^{-10} to 10^{-11} $cm^{-2}s^{-1}$ for E = 30 GeV) than satellite detectors, good angular resolution, acceptable energy resolution and a well tested capability to separate gammas from backgrounds. The MAGIC telescope is in its final commissioning phase and it is expected to start regular observations by the end of this year.

Apart from a wide variety of astrophysical sources of interest, like AGNs, pulsars, GRBs or SNRs, MAGIC is a suitable instrument for dark matter searches for neutralino annihilation signals from the Galactic Center and Local Group galaxies.

The Galactic Center is a crowded region containing sources that can emit also in gamma-rays (as a SNR, the most brilliant unidentified EGRET sources, ...). If diffuse gamma fluxes from annihilations are strong enough, as suggested by adiabatic compression models, observations displaced from the Galactic Center would be preferred. Also, we notice that the energy threshold of a Cherenkov telescope increases with the zenith angle Θ of the observation (this results in an energy threshold of 200 GeV for MAGIC in observing the Galactic Center). Because the very sharp energy spectral features, low zenith angle observations for Dark Matter searches are preferred. It is very attractive indeed that the effective areas are bigger, so that an improvement of the sensitivity is achieved.

4. Summary

Extensive montecarlo understanding of he detector response at different zenith angles is being done as well as taking into account the most important background sources as the cosmic proton, electron and Helium fluxes, the galactic diffuse gamma radiation as well as the expected annihilation signal one may expect in different scenarios. This will allow us to select which region is preferable for observations related to Dark Matter searches within the Milky Way halo.

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